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(54) Narrow beam scanning radar or lidar

(57) In an object detection system in which pulsed electromagnetic radiation is transmitted in a narrow beam which is scanned, e.g. rotated, the scanning rate is made so fast, in relation to the aerial beam width and pulse repetition rate, that the beam dwell time is less than the period between successive radiated pulses. The pulse repetition rate, for pulses of the same frequency is not an integral multiple of the scanning frequency. Beam positions in successive scans and thus at non coincident azimuths, and the full 360° area is only covered after several scan periods, successive echoes from a target being likewise spaced by several scan periods.

The invention is applicable to microwave radar systems or, to a pulsed laser system in which a narrow beam radiation from a laser 10 is scanned by a rotating scanner 11 at a scanning rate which is much higher than employed in conventional radar apparatus. This system enables the advantages to be obtained of the very narrow beam in giving good definition and minimising clutter but, because of the narrow beam and high scanning rate, imposes a maximum range for reception of signals reflected from the target or otherwise (e.g. jamming) locked to the transmitted pulses.

FIG. 1.

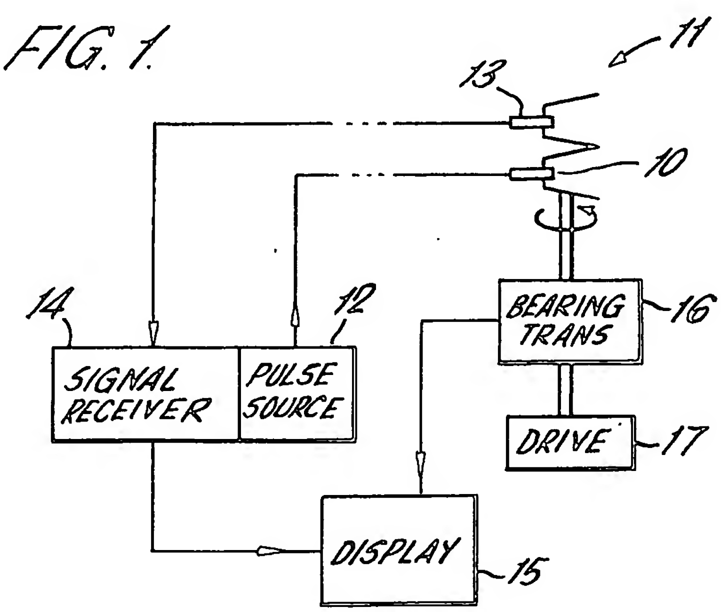

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FIG. 1.

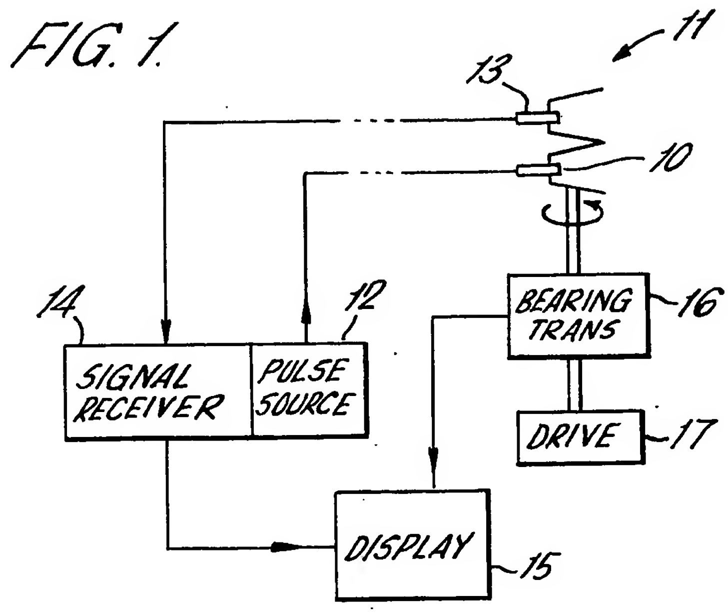
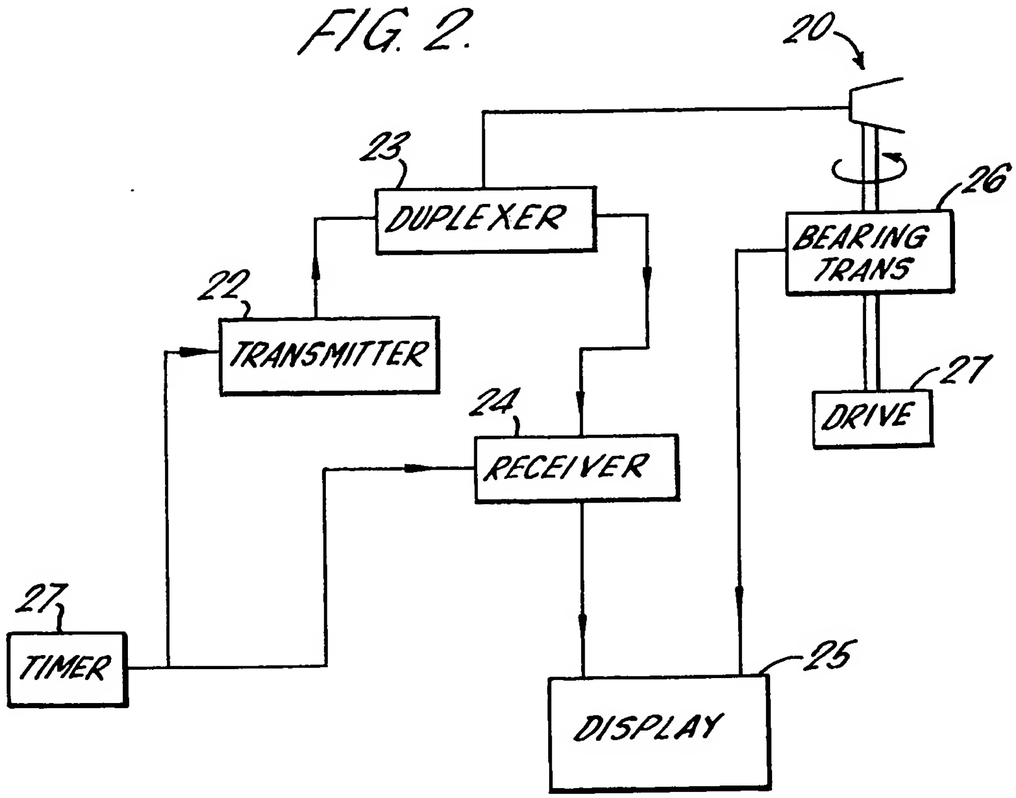

11
13
10
14
12
16
BEARING TRANS
SIGNAL RECEIVER
PULSE SOURCE
DRIVE
17
DISPLAY
15

FIG. 2.


20
23
26
DUPLEXER
BEARING TRANS
22
TRANSMITTER
27
DRIVE
24
RECEIVER
27
TIMER
25
DISPLAY

SPECIFICATION

Object detection apparatus using electromagnetic radiation

This invention relates to object detection apparatus using electromagnetic radiation.

It is well-known in pulse radar apparatus to provide a pictorial presentation indicating the positions of detected objects by using a narrow beam aerial for transmitting pulses of microwave energy and for receiving reflected signals, the beam being scanned, e.g. by rotation of an antenna. The use of a very narrow beam gives significant advantages, notably in accuracy and in reduction of clutter on the display. Narrow beams are more conveniently obtainable using higher frequencies. With pulse lasers or infra-red radiation however such scanning techniques have not heretofore been employed. It is known for example to make use of lidars employing a pulsed light source for establishing the height of a cloud base above the ground. Here the target is extensive in area normal to the beam from the pulse source and there is no need therefore for any rapid scanning of the beam to form an image. Commonly the beam would be kept stationary pointing vertically upwards.

With a very narrow beam, such as can be obtained for example with a laser, an image of distant objects cannot be produced in the same way as with, for example a microwave radar apparatus, because of the incompatability of achieving a sufficiently high data rate with the use of a narrow beam which will miss a target if it is scanned too quickly. In the radar art it is common practice to refer to the "beam dwell time"; this term is used to describe the time a scanning beam has to remain on a given target for satisfactory detection to take place. In order to give satisfactory display on a cathode ray screen or to provide data for digital data processing, it is necessary to make use of more than one target return as a single target return can be confused with a random pulse of noise. In radar systems therefore, the practice has been to ensure that the target remains illuminated by the beam for several pulse periods as the beam is scanned across the target so that a succession of returned signals are received from each target during each scan. With a step-scan radar in which the scanning is effected in steps, the beam dwell time is clearly defined. More commonly radars are of the continuous scanning type and a moving beam may be considered to have a dwell time corresponding to the time between the passage of the leading and of the lagging edges of the beam over a point target. The problem is more clearly explained by considering a specific example. In a radar with an azimuthal resolution of 2° (as would be the case with a four-foot aperture aerial at a wavelength of 3.2 cm) and with an aerial rotation speed of 20 r.p.m., then the beam dwell time, that is the time taken for the beam to scan across a point target, is 16.6 m secs. With a pulse repitition rate of 500 pulses per second there is, in this sample time, an opportunity to transmit and receive eight separate pulses. If one now considers a laser beam 0.2° wide, then, with the same scanning frequency, the beam dwell time drops to 1.6 m.secs. and the pulse repetition rate would need to be raised to 5000 per second to allow the same number of pulses to strike each target during each sweep of the beam across the target. A pulse repetition rate of 5000 per second restricts the unambiguous range to about 20 statute miles and hence gives problems due to longer range targets "folding over" into the display to appear in shorter ranges. There is also a practical problem in producing a transmitter at the higher pulse repetition rate.

According to the present invention, in apparatus for the detection of objects by repetitive transmission of short duration pulses of electromagnetic radiation, employing a scanning antenna system having a beam width θ (in radians) in the plane of scanning, the scanning being at an angular rate corresponding to N r.p.m., the pulse repetition rate is at a frequency n per second where n is less than $\frac{\pi N}{30\theta}$ and is not an integral multiple of N. Preferably n is much less than $\frac{\pi N}{30\theta}$, for example less than 1/10th of that value.

It will be immediately apparent that, with this system the beam dwell time is $\frac{30\theta}{\pi N}$. The period between transmitted pulses is greater than this and hence there is not necessarily any pulse transmitted during the beam dwell time on any specific target as the beam scans across the target. If n is 1/10th of $\frac{\pi N}{30\theta}$, then, on average, one would expect to get a target return from a given target once in every ten scans across the target. For simplicity, it is convenient to consider a system in which the scanning is continuous rotation at a uniform speed of N r.p.m. Thus, in order to obtain a data rate of once per second, it will be necessary to have 10 scans per second, that is the scanning rate N is 600. The system may be visualised by considering, for example, a scanner at 600 r.p.m. with a pulse repetition rate of only 1000 pulses per second, that is 100 pulses per aerial revolution. In one revolution, target information will be received from 100 discrete sectors evenly spaced around the transmitter, the width of each of the sectors being determined by the aerial beam width. These 100 sectors are like the radial threads of a spider's web and this spider's web pattern will slowly rotate at a rate determined by the difference frequency between the pulse repetition rate, in this case 1000, and the hundredth harmonic of the aerial rotation speed.

It will be noted however that, although particular mention has been made, by way of example, to the use of a continuously rotating scanner, the invention is equally applicable to a sector scanning system.

It will now be apparent that this system enables a plan position display or other equivalent presentation of the radar data to be provided despite any practical limitations on the maximum repetition frequency of the pulse transmitter.

There is a further important advantage of this type of object detection system in that there is a finite maximum range from which signals can be received. This arises from the finite time taken for a pulse of electromagnetic energy to travel from the transmitter to the target and back. This time is referred to as

the flight time. For a range R, if the velocity of propagation is c, the flight time is 2R/c. Consider for example a scanner operating at 600 r.p.m. with a beam width of 0.2°. The beam dwell time in this case is 160 microseconds and this corresponds to a radar flight time of about 15 statute miles. It is not possible to detect any targets beyond this range because, at longer ranges, the aerial beam has moved away from the target at which it was pointing when the transmission took place. More generally, the maximum range is $\frac{15c\theta}{\pi N}$, it will be noted that the pulse repetition period does not impose a lower maximum because the pulse repetition period is greater than $\frac{30\theta}{\pi N}$. It will be appreciated however that targets at the maximum range can only be detected if the transmission takes place just as the leading edge of the beam begins to point at the target so that the return signal can be received just before the lagging edge of the beam leaves the target. At this range therefore there is a reduced probability of obtaining a target in any one scan. For practical purposes therefore the system is suitable for use for detection of targets at ranges substantially less than the theoretical maximum. There is no problem of longer range targets folding over into the display; this is prevented by the movement of the aerial beam. This range limitation is of particular importance in military radar since it prevents jamming by a repeater jammer at long range. Such a jammer receives the transmitted signal and re-transmits it as a long duration pulse covering a number of successive pulse repetition periods of the radar. Such a jammer may be used for example against a conventional pulse radar to screen an intruder approaching on a specific bearing. The apparatus of the present invention, however, by the range limitation, does not receive such a jamming signal.

It will be immediately apparent that the apparatus of the present invention may operate not only on microwave frequencies, particularly very high frequencies such as for example on Q-band, but may also be used with pulse transmission of visible light or infra-red radiation, for example using a pulsed laser.

In practice, it is desirable to use a high speed scanner, typically for example operating at 600 r.p.m. On a plan position display, a static target will not appear on each scan but only, as explained above, on a small faction of the scans. Such a target therefore will appear to twinkle with a high speed scan. A moving target which does not produce spot overlap on the display when returns are received from that target, will not twinkle at all. A slow moving target will twinkle much less than a static target. It will be seen therefore that a plan position display on a cathode ray tube provides a ready means for differentiating between moving targets and static targets without requiring any additional signal processing equipment.

The transmitted pulses may be all of the same frequency. Particularly with a microwave system, the pulses may be at two or more different frequencies in a cyclic sequence, the pulse repetition rate at each frequency being n per second. In other words two or more different radio frequencies can be used with the pulses interlaced sequentially. The time intervals between the pulses need not necessarily be equal. By using m different frequencies, the data rate is increased by a factor of m assuming the other parameters are unchanged. The use of multiple frequencies however would enable, for example, the scanning speed to be reduced and hence the maximum range to be increased whilst still giving the same protection against long range jamming transmitters.

The invention furthermore includes within its scope apparatus for the detection of objects by transmission of short duration pulse of electromagnetic radiation and receiving reflections of those pulses using a narrow beam transmitting and receiving aerial which is scanned angularly wherein the beam dwell time due to the angular scanning is substantially less than the duration between successive pulses of the same frequency and wherein the pulse repetition rate for pulses of the same frequency is not an integral multiple of the scanning frequency.

This type of object detection equipment finds particular application for ground-based or shipborne apparatus for short range target detection. On an aircraft it finds particular application, especially using a pulsed laser beam, for ground or ocean mapping or for vehichle or ship detection. The use of a pulsed laser with scanning as described above enables very high angular resolution to be obtained which is far better than that of a microwave scanning radar. It is an active detection system as distinct from a system giving pictorial images such as have been produced heretofore by forward-looking infra-red equipment on aircraft, which equipment acts in a purely passive capacity and is therefore much less sensitive than the system of the present invention.

Although reference has been made particularly to more scanning by continuous rotation at uniform speed, it will be immediately apparent that the invention is equally applicable to systems which scan through a limited angle; provided the angular rate of movement of the scanning beam, in relation to the beam width and pulse repetition rate, is sufficiently fast, the advantages of the present invention are obtained, in particular, the limited maximum range of reception and protection against jamming.

In the following description, reference will be made to the accompanying drawings in which Figures 1 and 2 are diagrams illustrating two different embodiments of the invention.

In the embodiment shown in Figure 1 a pulsed laser 10, which may operate in a visible or for example in the 3 to 5 μm or 10 to 15 μm wavelength band, is mounted on a rotatable scanner 11 for continuous rotation, typically at a speed of the order of 600 r.p.m. The laser produces a beam having an angular width which is a small fraction of a degree. A cylindrical lens is provided in front of the laser so that the beam is broadened in the vertical plane and thus scans targets above and below the plane in which the beam rotates. This is necessary not only when the scanner is on a moving platform, e.g. on a ship or aircraft, but also because, even if the

platform is stabilised, such broadening is necessary to detect targets on a rough surface. The laser repetition rate is controlled by a pulse generator 12 and might typically be of the order of 1000 pulses per second. Mounted also on the scanner 11 is a receiver 13 for detecting return signals reflected from distant targets, which signals are processed in a receiver and signal processor 14 and displayed in display apparatus 15. The receiver, like the laser, has a fan-shaped beam with angular spread in the vertical plane. The display apparatus, in its simplest form, may comprise a cathode ray tube plan position display, the received signal being processed in the known way to produce a video output applied as brightness modulation onto a display trace which is rotated in synchronism with the rotation of the scanning aerial 10 by means of a bearing transmitter 16 coupled to the aerial drive 17 and providing signals for controlling the position of the display trace on the screen. The display however differs from a conventional radar display in appearance because a very much higher rotational scanning speed is employed. From any given target, a signal return will only be received on some of the scans of the radiated beam through the target position. As a result, on the display, static targets will twinkle but whereas moving targets, if they are moving sufficiently fast, will not twinkle at all. The apparatus has a finite maximum range, as explained previously, giving protection against stand-off jammers operating beyond that range. These advantages are obtained in addition to the advantages of good definition, high accuracy and reduced clutter which arise because of the very narrow beam produced by the pulsed laser compared with microwave scanning systems of floodlit passive pictorial infra-red systems. Even if a microwave radiation is employed, the finite maximum range and consequent protection against distant jammers is obtained.

Although a mechanically scanned system has been more particularly described, the invention may be applied to systems using other types of scanning, e.g. electronic scanning may be employed to obtain the required high speed scan for a microwave radar.

With a microwave radar, it is readily possible to obtain a sufficiently high pulse repetition rate, typically in excess of 500 pps, to give a good data rate. With lasers, in the present state of the art, the laser itself may have limitations resulting in a much lower pulse repetition rate. It will be seen however that the present invention permits of a plan position display being obtained, even with a low transmitted pulse repetition rate; the high speed scan together with the narrow beam gives the protection against distant jammers.

Figure 2 illustrates a microwave radar system having a narrow-beam directional antenna 20 which is continuously rotated or is scanned repetitively over a sector by a drive motor 21. A transmitter 22 including a magnetron or other radio frequency pulse generator arranged for generating repetitive short duration pulses of radio frequency energy feeds the antenna 20 via a duplexer 23 and received echo signals picked up by the antenna are fed via the duplexer to a receiver 24. Video output signals for receiver 24 are fed to a display 25 to which is also fed bearing information from a bearing data transmitter 26 representative of the antenna direction. The display is typically a brightness-modulated display, e.g. a P.P.I. or B-scope display.

The antenna scanning rate would typically be of the order of 600 r.p.m., which is much faster than is commonly used for microwave radar systems. The radio frequency signals might typically have a pulse repetition rate of 1000 pulses per second. However this pulse repetition rate is not an integral multiple of the antenna scanning frequency so that, on each successive scan, the angular positions of the antenna at which pulses are radiated differ from the directions of radiation on the previous scan. Thus, as previously explained, on any one scan targets will be detected over a limited number of discrete sectors evenly spaced around the transmitter, the width of each sector being determined by the antenna beam width. This pattern of sectors will slowly rotate with successive scanning cycles.

In this particular embodiment, shown in Figure 2, the magnetron or other radio frequency pulse generator employed in the transmitter 22 is capable of radiating in cyclic sequence pulses of two or more differing microwave frequencies under the control signals from a timing unit 27. Typically, the transmitter can radiate on four frequencies. The timing unit 27 also provides the necessary synchronising signals to the receiver 24. The time intervals between the successive pulses in a sequence of different frequency pulses need not be equal and likewise there is no necessity to have a constant time interval between the pulses on any one frequency. However the protection against any jamming transmissions locked in time to the radiated pulses comes from the high antenna rotation speed in relation to the beam dwell time. As previously explained, this gives a maximum range of detection; locked signals would not be received from stand-off jammers beyond that range. With a beamwidth of 1 degree, and a rotation rate of 600 r.p.m., the maximum range is about 41 kilometres and a working range of about 20 kilometres would be obtained.

CLAIMS

1. Apparatus for the detection of objects by repetitive transmission of short duration pulses of electromagnetic radiation and employing a scanning antenna system having a beam width θ in the plane of scanning, wherein the scanning is at an angular rate corresponding to N r.p.m. and wherein the pulse repetition rate is at a frequency n per second, where n is less than $\frac{\pi N}{30\theta}$ and is not an integral multiple of N.

2. Apparatus as claimed in claim 1 wherein the transmitted pulses are all of the same frequency.

3. Apparatus as claimed in claim 1 wherein the transmitted pulses are at two or more different frequencies in a cyclic sequence, the pulse repetition rate at each frequency being n per second.

4. Apparatus as claimed in any of claims 1 to 3 wherein n is substantially less than $\frac{\pi N}{30\theta}$.

5. Apparatus as claimed in any of claims 1 to 3

wherein n is less than 1/10th of $\frac{\pi N}{300}$.

6. Apparatus as claimed in any of the preceding claims and having a plan position cathode ray tube display to which the received signals from the antenna are fed as a brightness modulation of a trace rotated in synchronism with the antenna.

7. Apparatus as claimed in any of the preceding claims wherein the short duration transmitted pulses are pulses of microwave radio frequency radiation.

8. Apparatus as claimed in any of claims 1 to 7 wherein the short duration pulses are pulses of light or infra-red radiation.

9. Apparatus for the detection of objects by transmission of short duration pulses of electromagnetic radiation and receiving reflections of those pulses using a narrow beam transmitting and receiving aerial which is scanned angularly wherein the beam dwell time due to the angular scanning is substantially less than the duration between successive pulses of the same frequency and wherein the pulse repetition rate for pulses of the same frequency is not an integral multiple of the scanning frequency.

10. Apparatus as claimed in claim 9 wherein a pulsed laser is provided for producing said short duration pulses.

11. Apparatus as claimed in claim 9 wherein the transmissions comprise repetitive pulses of the same frequency.

12. Apparatus as claimed in claim 9 wherein the transmissions comprise a repetitive cyclic sequence of pulses of two or more different frequencies.

13. Apparatus as claimed in any of claims 9, 11 or 12 wherein the transmissions are short duration pulses of radio frequency energy.

14. Apparatus substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

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